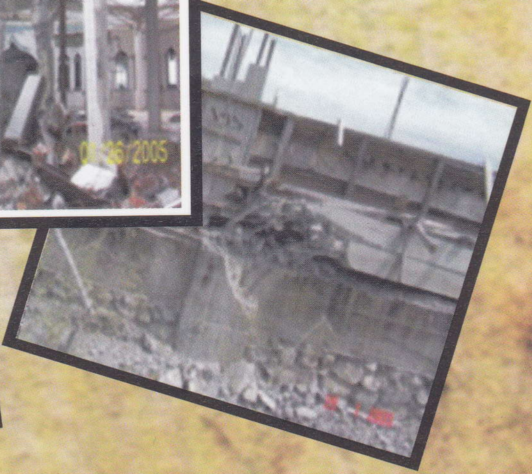
SEISMIC DESIGN OF BUILDINGS

Effect of Earthquakes and Design Provisions

Herman Parung



Badan Penerbit UNM

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Preface

As can be noticed and seen from different media such as TV, internet and newspaper in the last several years, thousands of people die every year, directly or indirectly, due to earthquakes. An earthquake can cause not only the collapse of a structure, but also its destruction due to gas explosion and resulting fire.

As a researcher focus mainly on the seismic design of buildings, I have visited several devastated areas after the earthquakes in Indonesia such as Nabire in Papua, Padang, Jogyakarta, Aceh and lastly Sendai in Japan. It can be witnessed that proper design of buildings could avoid or reduce casualties while improper design causes collapse of buildings and casualties.

This book presents results of extensive research that have been undertaken in several different laboratories and also from direct observations on site to describe the effects of earthquakes to many structures. Design provisions for seismic resistant reinforced concrete and steel structures and also base isolated buildings are also described in this book. However, design codes will not be described in detail in this book. Readers are advised to refer directly to the codes if considered necessary.

There is a possibility that this book contains grammatical errors and also some inconsistency regarding the scientific contents. These errors will be checked and taken care of in the next edition, which will be called revised edition. Examples of detail designs of steel or concrete buildings will be included in the revised edition in the near future.

I hope that this book can add valuable information to researchers, undergraduate and graduate students, and also to design engineers who practice in the seismic design of buildings.

This book is dedicated to my late wife (Luciana) who passed away on the 18th May 2008, and three children (Gaby, Gary and Deby) who supported me during my studied abroad. Without them, this book, which is based on my previous research abroad could not be materialized.

Makassar, May 18th, 2012

Herman Parung

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Thousands of people die every year, directly or indirectly, due to earthquakes. An earthquake could cause not only the collapse of a structure, but also its destruction due to gas explosion and resulting fire. In the last couple of years, earthquakes caused loss of life in Japan, China, Indonesian, and other parts of the world.

Structures usually perform differently to the earthquakes' excitations. Some structures will withstand earthquakes without major damages, but other structures may collapse totally. The destructive effects of earthquakes depend upon several factors, for example the magnitude of the earthquake (usually measured on the Richter-scale or MMI-scale), the stiffness, the mass, and the natural period of the structure, and the capability of the structure to absorb and dissipate the earthquake input energy.

The designer can consider various levels of structural protection and develop his design accordingly. Some criteria such as preserving the functionality of a building under limited earthquake exposure and the prevention of total collapse or destruction under extreme earthquakes in order to prevent the loss of life are the basic design conditions. In aiding the structural engineer in meeting those criteria, present day codes are developed to meet these basic conditions.

In fact, the performance of a structure designed according to those code provisions, will meet the following three basic limit states conditions:

a. serviceability limit state

Relatively frequent earthquakes inducing comparatively minor intensity of ground shaking should not interfere with the functionality of the building. Hence, structural damage is to be avoided by designing for adequate strength in all components of the structure. Under earthquake-induced inertia forces, the structure will remain essentially elastic. Sufficient stiffness is needed to prevent large displacements of a structure. Damages needing repair of structural and non-structural elements should not occur.

b. damageability limit state

For ground shaking of intensity greater that that corresponding to the serviceability limit state, some damage damages to structural and non-structural elements may occur. Some local yielding of steel or reinforcing steel as well as spalling and crushing of concrete are allowed. Buildings are expected to be repaired easily and to be reinstated to full service.

CHAPTER 2

THE EFFECTS OF EARTHQUAKE TO BUILDINGS

2.1 GENERAL

In the past ten years, Indonesia has experienced several major earthquakes. The large earthquakes have caused not only casualties but also damage to engineered and non-engineered buildings. This chapter presents damage assessment on buildings at several locations, namely Nabire (Papua), Toli-*Toli (Central Sulawesi), Banda Aceh and Simeulue (NAD) and Padang (West Sumatera).*

The assessment shows that most of the damaged buildings have very similar type of damages, and the damages actually could have been avoided by better implementation of design code. The supervision of the building construction on the remote areas has to be improved, because it has been observed that even during the reconstruction of damaged buildings, the new buildings are still vulnerable to new earthquakes.

In the year 2004, Nabire district of Papua was hit twice by strong earthquakes. The first earthquake occurred on 6 February 2004 and the second one occurred on 26 November 2004. Both earthquakes have caused collapsed of buildings and casualties. On Wednesday 20 February 2008, western Sumatera was hit by a shallow major (strong) earthquake with the magnitude of 7.3 on the Richter scale, followed by several smaller earthquakes. Several people witnessed that the earthquake felt in three different directions, namely two horizontal directions and one vertical direction. The total houses damaged were reported 1,350 unit; 455 units were heavily damage while 895 units had light damage (Kompas daily, 23 February 2008). Several buildings near the building under consideration were totally collapse.

A one-story house approximately 150 m from the building was totally collapse. Also, a *puskesmas* (community health center) building, a police resort under construction and the newly completed Pendopo Kecamatan were collapsed. This fact indicates that the MMI (Modified Mercally Intensity – MMI) in this particular area was high. On September 30, western parts of Sumatera, especially around Padang and Pariaman was also hit by an earthquake measured 7.9 on the Richter scale. The high number of casualties and buildings collapse (modern and non-engineered) attracted many intention so live coverage on TV screen for several days could be viewed.

It can be witnessed from direct observation, that many buildings were partially or completely damaged. The types of damages were common for each area considered in this study.

2.2 Damage Assessment - Nabire Earthquake

As mentioned above, earthquakes that hit the region of Nabire in Papua in 2004 had left casualties and also damage to buildings (Parung, Ref 74). Figure 2.1 shows the intensity of the earthquake (*Kompas* daily)..

CHAPTER 3
DETERMINATION OF SEISMIC FORCES

3.1 Method of Analysis

Designing of a structure to resist earthquake forces normally be based on the expected magnitude of excitation induced by an earthquake. However, the exact forces can not be accurately estimated, as the occurence of earthquakes are also difficult to determine.

It is important to realize that the earthquake forces estimated in the design will influence heavily the cost of the construction. Normally, if the probability of occurence is longer, for instance 500 years, the force induced will be higher than the force induced by a shorter return period of an earthquake.

As mentioned in the previous sections, the effects of earthquakes to structures depend on several factors such as size of earthquake, distance from the site, soil characteristics and type of structures. Moment resiting frames, for example, will response to earthquakes in different manner from brcaed frames.

The design force normally can be determined using static or dynamic analysis. The equivalent static force normally applied for a regular structure, while dynamic analisis is more appropriate for irregular buildings.

3.1.1 Static Analysis

In the static analysis, the force will be treated as equivalent static, which means that the dynamic earthquake force will be treated as static force. Because the nature of the earthquake is actually dynamic, the approach is then called equivalent static.

The inertial forces induced by earthquakes are specified as static forces using formulas, which are usually empirical. The formulas used are basically similar for different design codes, although the variation in several coefficients are also present due to different characteristics of earthquakes and soil conditions.

It is should be emphasized that the formulas developed have been carefully chosen in order to represent the dynamic behavior of regular structures. The regular structures are considered to have uniform mass and stiffness, and determination of lateral forces using equivalent static method is considered adequate. Normally, each code also specifies the use of accidental torsion factor to take into account the possible torsion due to the difference between the centre of mass and centre of inertia.

CHAPTER 4

DESIGN OF REINFORCED CONCERETE

4.1 General

Design of reinforced concrete structures is basically aimed at preventing the structures from collapse in the event of strong earthquakes. However, in the event of moderate earthquakes, repairable damages to the elements of the structures are acceptable.

As mentioned in design codes, the most difficult for designing any seismic resistance structures is the determination of design force, or demand (Ref. 63). If the demand is already high, the structures can be designed to possess sufficient capacity to meet the demand.

In case of reinforced concrete structures, detailing of members is very important to ensure that strength and ductility can be maintained in case of earthquakes. Proper design and detail, as shown in the several earthquakes, can ensure that strength, stiffness and ductility can be achieved even under strong earthquakes.

One way to achieve the so-called good design is to design a structure such, that the yielding sequence will prevent the building from early collapse or damage. Structures with considerably regular and symmetrical plan and limited eccentricity would normally possess higher ductility than irregular buildings.

It is a common practice to design a reinforced concrete structure to respond in-elastically in case of moderate-to-strong earthquake, because elastic design will be considered uneconomical. This can be achieved if the structures possess adequate ductility to allow energy dissipation through inelastic deformation or yielding.

Ductility of structures depends on the performance level considered, for elastic structures will be equal to 1.0. For fully ductile structures, the use of ductility factor = 5.3 is adopted. One way of ensuring the ductility is to provide structural redundancy, which can be easily achieved by providing continuity between elements of reinforced concrete resisting frames.

In Indonesia, design of reinforced concrete structures is based on the SNI – 03 – 2847 – 2002 – Design Method for Reinforced Concrete Building Structures. The code will not be described in detail in this section of the book, so it is recommended for the reader to refer the SNI if necessary.

Rachmat Purwono and Tavio (Ref. 99) have also prepared an evaluation procedure for Special Moment Resisting Frames, which can be used for assessing the compliance of the available design to SNI. The check list provided is easy to follow.

CHAPTER 5

DESIGN OF STEEL BUILDINGS

5.1 General

Design of steel buildings to resist seismic forces is described in Eurocode 8, which also includes special provisions to steel building. In Indonesia, detail design of steel structure and the determination of seismic load are found in relevant the SNI.

The description of the seismic design of steel presented in this book is mainly based on provision of Eurocode and supported by findings from the research on a three dimensional steel frame study.

5.2 MOMENT RESISTING FRAMES

Frames designed to resist moments activated by seismic loads are usually called ***Moment Resisting Frame***. It is not always necessary to design all frames, usually only one or two in each direction, to resist the seismic load; the rest are designed to resist the gravity load only.

Columns in moment-resisting steel frames have to resist the beam capacity moment. A problem rises when the actual yield stress of the steel beam is larger than the nominally specified stress. A safety factor of 1.2 is therefore used for the calculation of the moment-capacity of column, as mentioned in the Eurocode 8 (Ref. 15).

$$M_{column} \geq 1.2 \; M_{beam}$$

The MRF have large number of dissipative zones that are located near to the beam-to-column connections. They resist the horizontal forces in an essentially bending manner; and energy can be dissipative by means of cyclic bending behavior.

It is customary in the analysis to treat dead load and live load as separate load cases that they may be combined in the various load combinations with appropriate load factors or reductions. Most building codes permits a reduction factor of the design floor lives load for all structures framing members in recognition of the fact that it is unlikely that the entire floor area will be fully loaded at any time.

Unbalanced gravity loading in moment-frames induces sideways moments and shears that must be considered in the frame design. An additional secondary effect is that due to elastic column shortening. This effect is even more pronounced for the overturning forces due to wind or seismic forces.

MRF resists lateral loads by means of joint rotation that induces sideways moments and shears that must be considered in the frame members. Axial forces are also induced in the frame columns due to the overturning moments caused by the lateral

CHAPTER 6

BASE ISOLATED BUILDING

6.1 GENERAL

A structure which is subjected to an earthquake will generally respond to the earthquake in a similar manner to a single degree-of-freedom oscillator, namely the first mode dominates the motion.

Earthquake spectra (Figure 1.1) show that for most cases, a structure responds with high acceleration if the first mode periods are less than 1.5 seconds. So, by increasing the period in the structures, the response can be reduced (note that increasing the damping factor will also reduce the response).

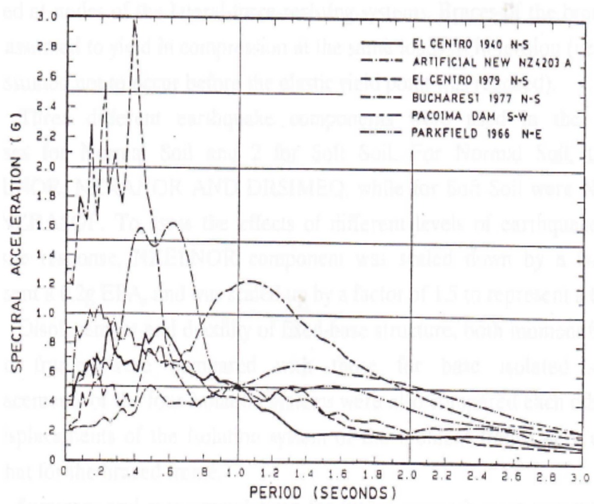


Figure 6.1 Earthquake Spectra

6.2 Basic Concept of Base Isolation System

Ground accelerations produced in the event of an earthquake are amplified in a structure by its dynamic magnification properties. This can cause damaging effects to the structure.

One way of reducing the seismic forces, and their damaging effects, is to decouple the structure from its base. Decoupling of the structure can be achieved by introducing additional flexibility at the base effectively increasing the period of the structure.

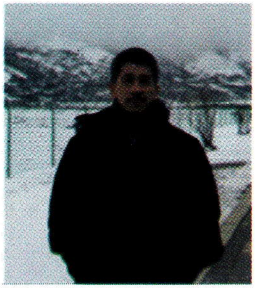
Typical strong motion acceleration spectra show that the longer, the period of the structure, the smaller the seismic forces. The basic concept of base isolation is to lengthen the period of the structure in order to reduce the seismic force. Various systems of isolation will be discussed further in the next section.

BIBLIOGRAPHY

APPENDIX 1. Classification of Earthquake

No.	Magnitude (Richter Scale)	Explanation
1	≥ 8	Great earthquake
2	7.0 – 7.9	Major earthquake
3	6.0 – 6.9	Destructive earthquake
4	5.0 – 5.9	Damaging earthquake
5	4.0 – 4.9	Minor earthquake
6	3.0 – 3.9	Smallest generally felt
7	2.0 – 2.9	Sometimes felt

**Source*: Badan Metereologi dan Geofisika (BMG) Indonesia



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He graduated as Masters of Engineering from the Department of Civil Engineering, School of Engineering, Auckland University, New Zealand in 1992, and graduated as Doctor Ingenieurs (Dr.-Ing) from the Institutfuer Stahlbau und Werkstoffmechanik, Technische Universitaet, Darmstadt, Germany in 1998.

His major interest is Design of Seismic Resistant Buildings. He also involves in the study on the behavior of Precast Construction and Fire Resistance of Steel Buildings.Currently he teaches Steel Structure, Earthquake Engineering, Prestressed Concrete Structures at S1 Program. For Masters and Doctor Degree Programs, he teaches subjects: Numerical Method, Ductile Behavior of Reinforced Concrete and Steel Structures.

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